

Superconducting Magnet Design

Dipole magnets

The long-term goal of High Field Magnet R&D program at Fermilab is the development of new generation superconducting accelerator magnets with the nominal operation field above 10 T, operation temperature 4.5 K and high operation margins for different applications including a future VLHC, upgrades of Tevatron, LHC, etc.

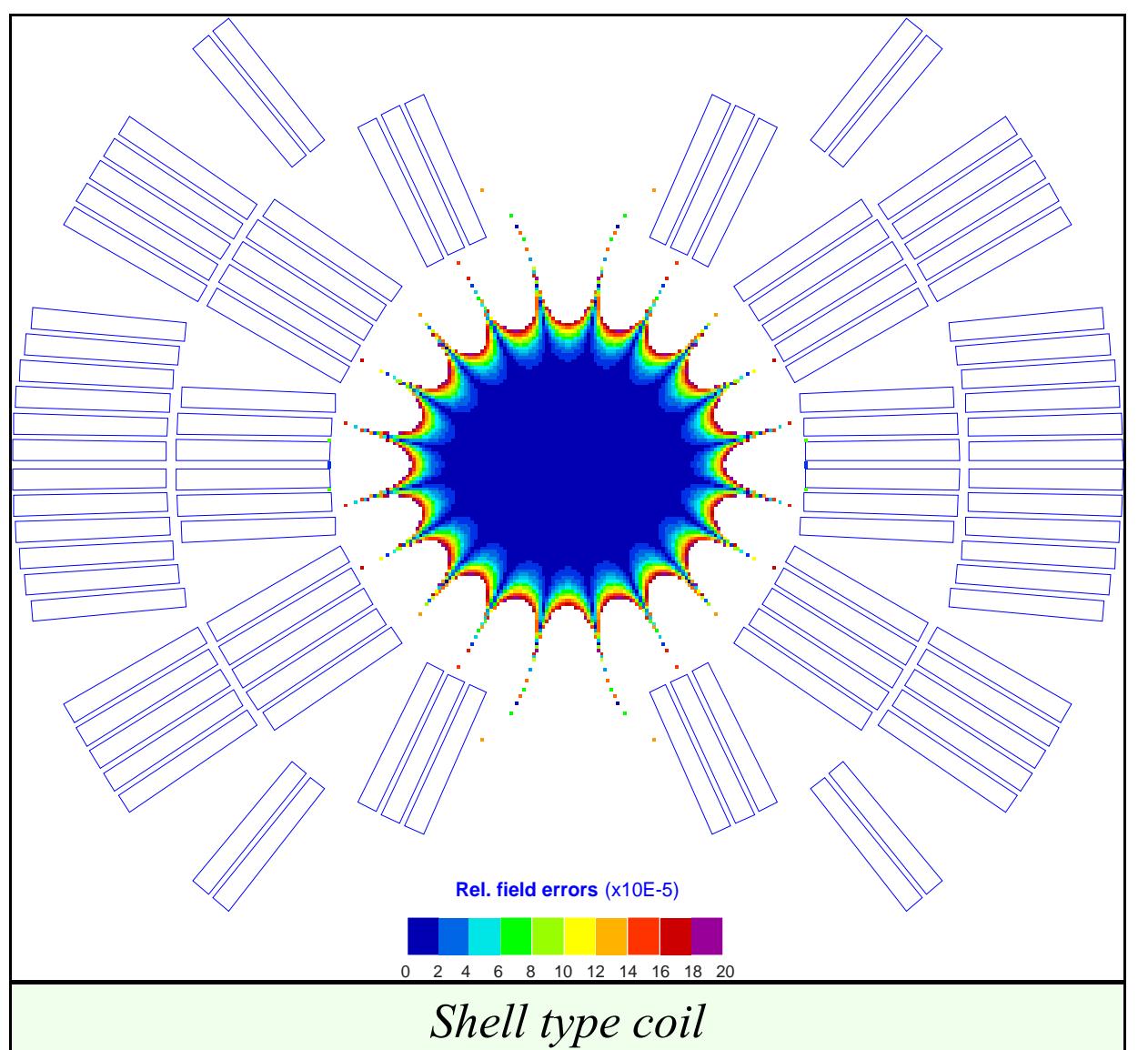
- Magnet requirements for upgrading existing and future machines push accelerator magnet technology to the limits not achievable with NbTi conductor.

Fermilab is investigating 2 types of high field dipole designs based on:

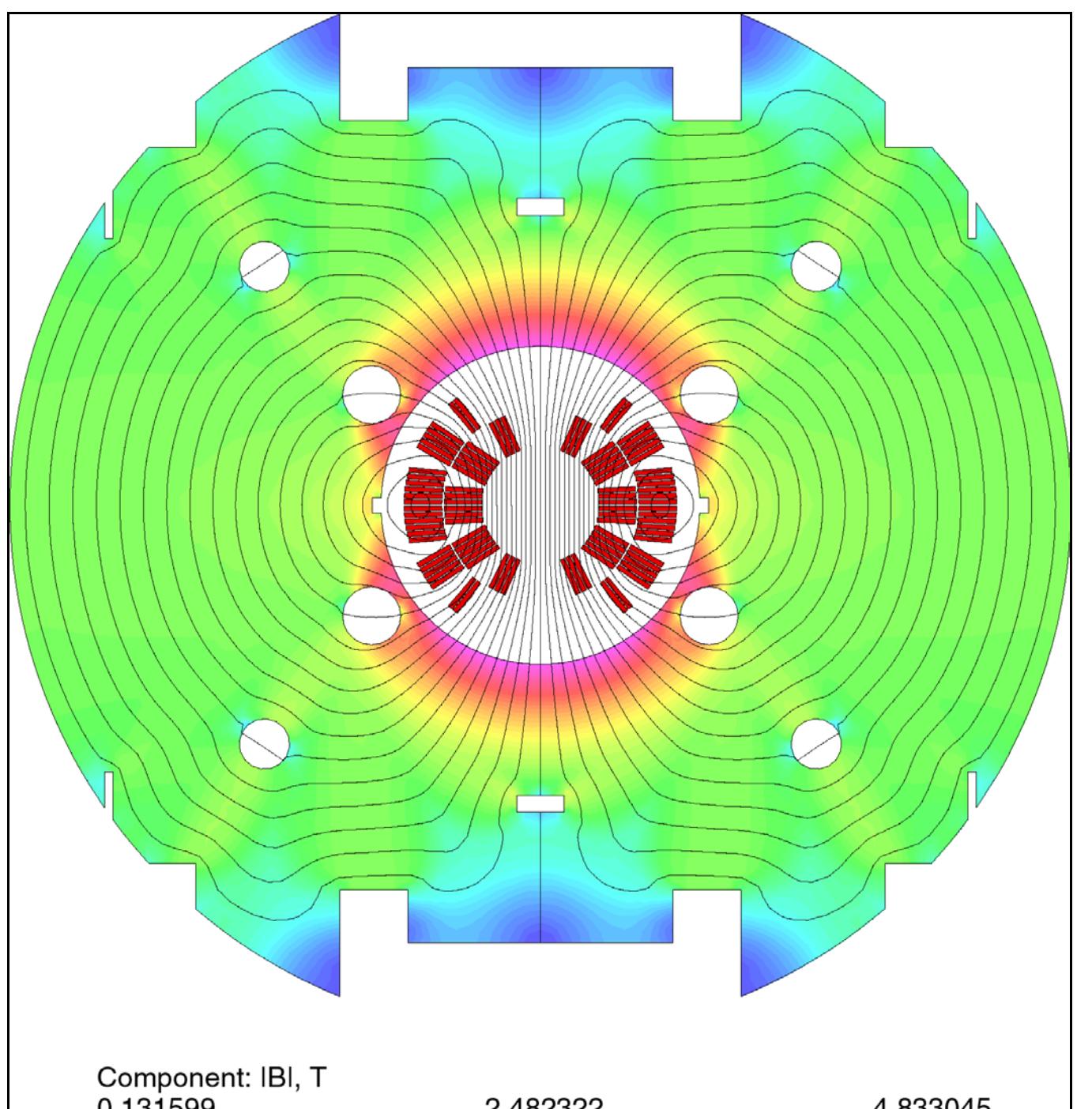
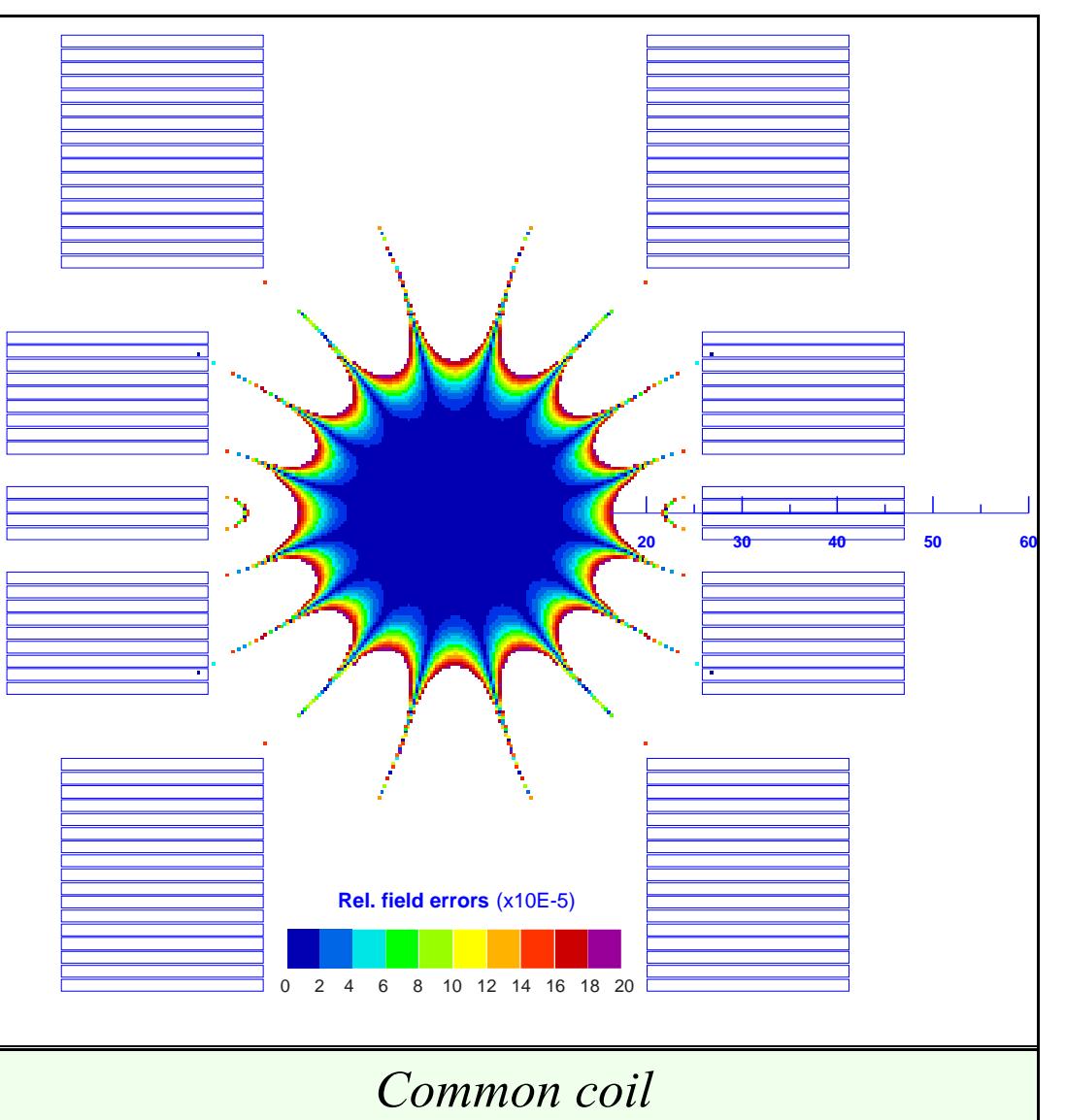
- traditional shell type coils with a cos-theta azimuthal current distribution;
- flat block-type coils arranged in the common-coil configuration;
- in this innovative design approach the conductor bends are relatively gentle and friendly to brittle conductors such as Nb₃Sn or HTS.

At present time the HFM R&D program is concentrated on:

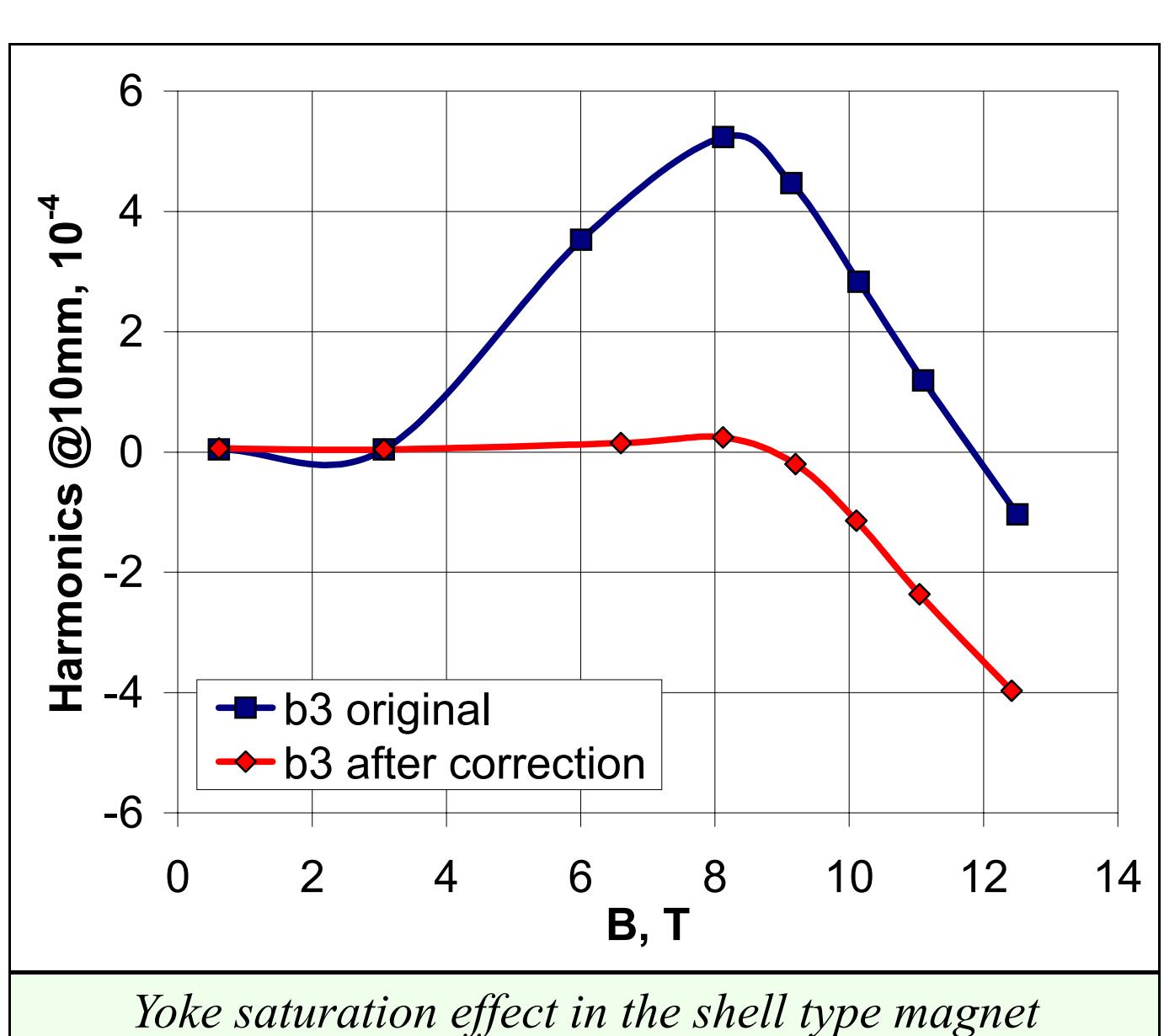
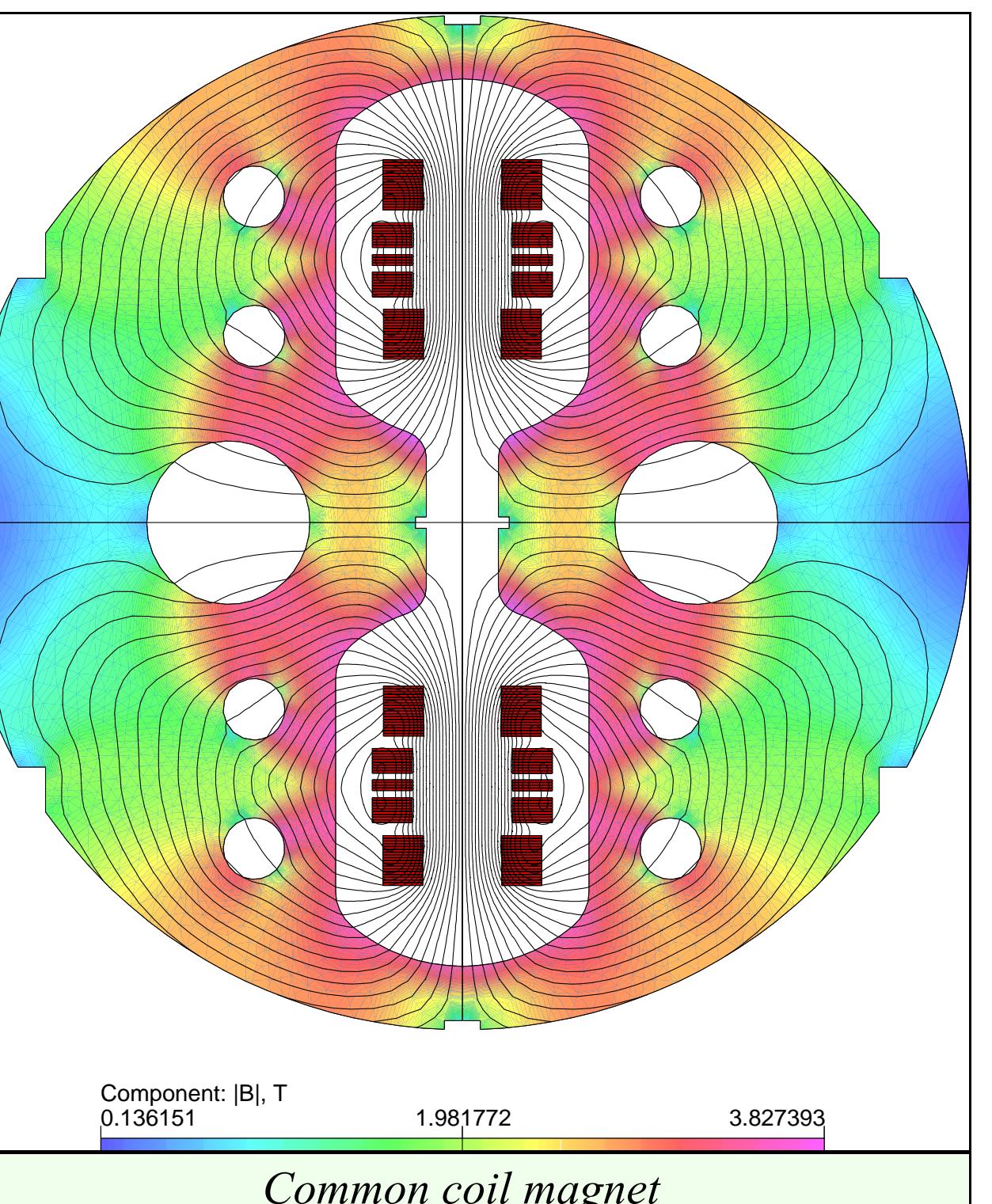
- development of 11-12 T accelerator magnets based on Nb₃Sn superconductor;
- commercially available but difficult material due to its brittleness.
- exploration of two basic magnet technologies used for brittle superconductors - wind-and-react and react-and-wind;
- each has its challenges → long development time is required.



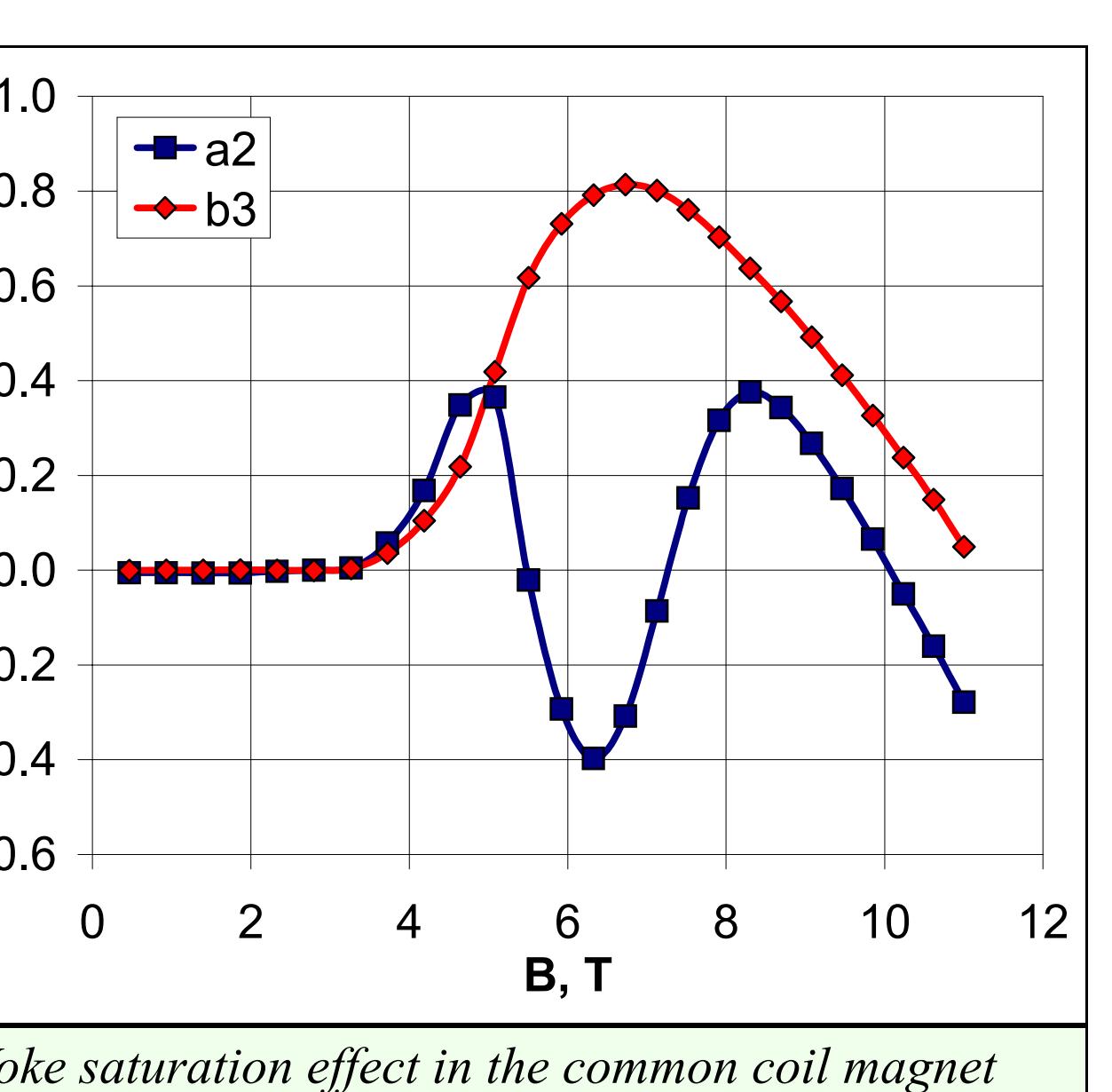
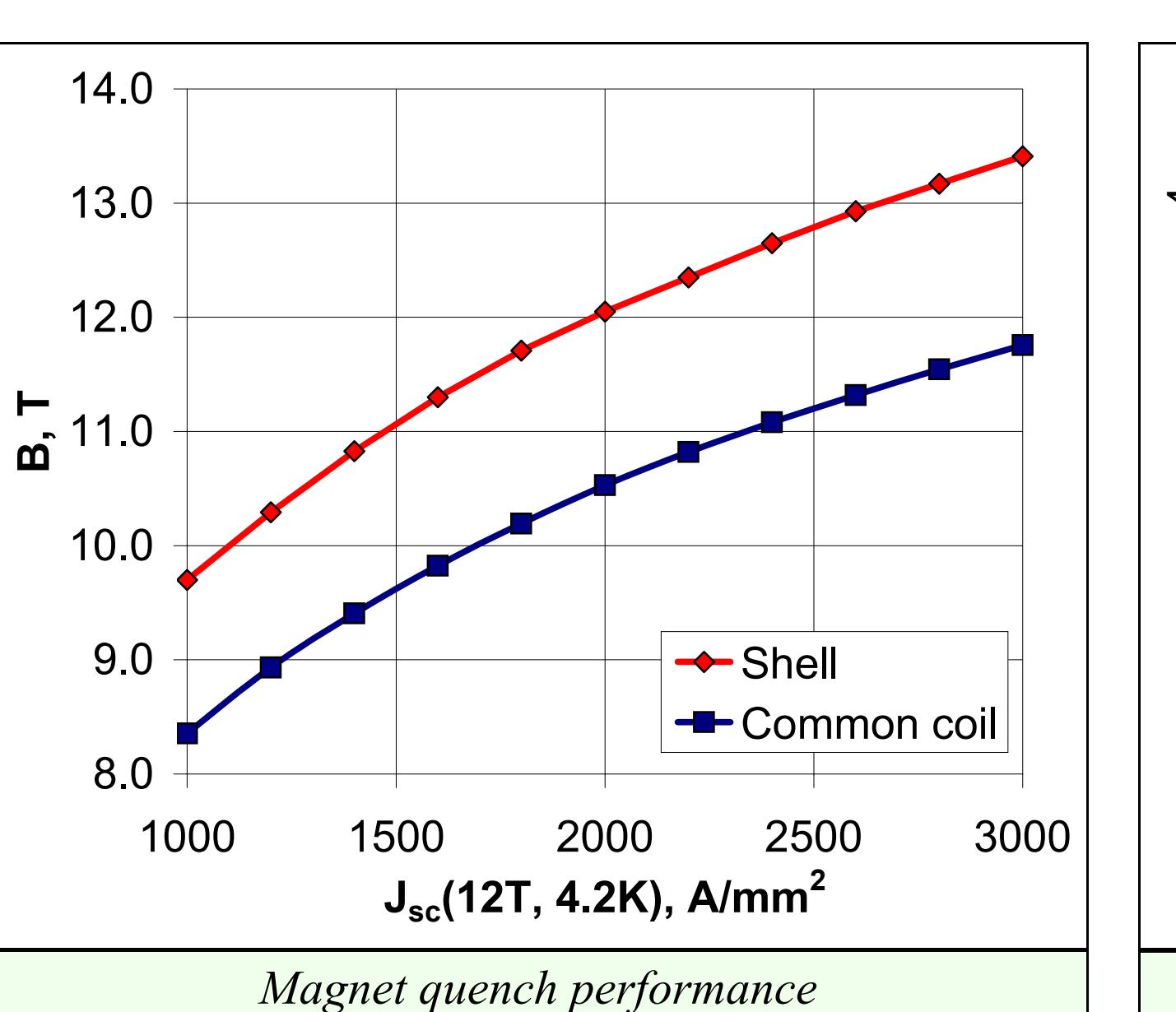
Geometrical and random (+/- 50 μm) harmonics at 10 mm radius			
n	Shell	Block	
1	10000	-	10000
2	-	1.20	-
3	0.000	0.56	-0.002
4	-	0.28	-
5	0.000	0.10	0.000
6	-	0.05	-
7	-0.000	0.02	0.014
8	-	0.01	-
9	-0.091	0.00	-0.048
10	-	0.00	-
11	0.099	0.00	0.001



Magnet parameters			
Parameter	Units	Shell	CC
Number of apertures	-	1	2
Aperture diameter	mm	43.5	40.0/51.6
Bore separation	mm	-	290
SSL @12T, 4.5K	A/mm ²	2200	2200
Cu/non-Cu ratio	-	0.85	0.85
Quench field	T	12.35	10.82
Quench current	kA	22.9	25.5
Tr. function @11 T	T/kA	0.55	0.42
Inductance @11 T	mH/m	1.31	2x1.47
Stored energy @11 T	kJ/m	263	2x498
Coil area	cm ²	22.3	2x26.8
Iron OD	mm	400	580



Yoke saturation effect in the shell type magnet



Yoke saturation effect in the common coil magnet

LARP quadrupole magnets

A goal of the U.S. LHC Accelerator Research Program (LARP) is to develop 2nd generation IR magnets for LHC.

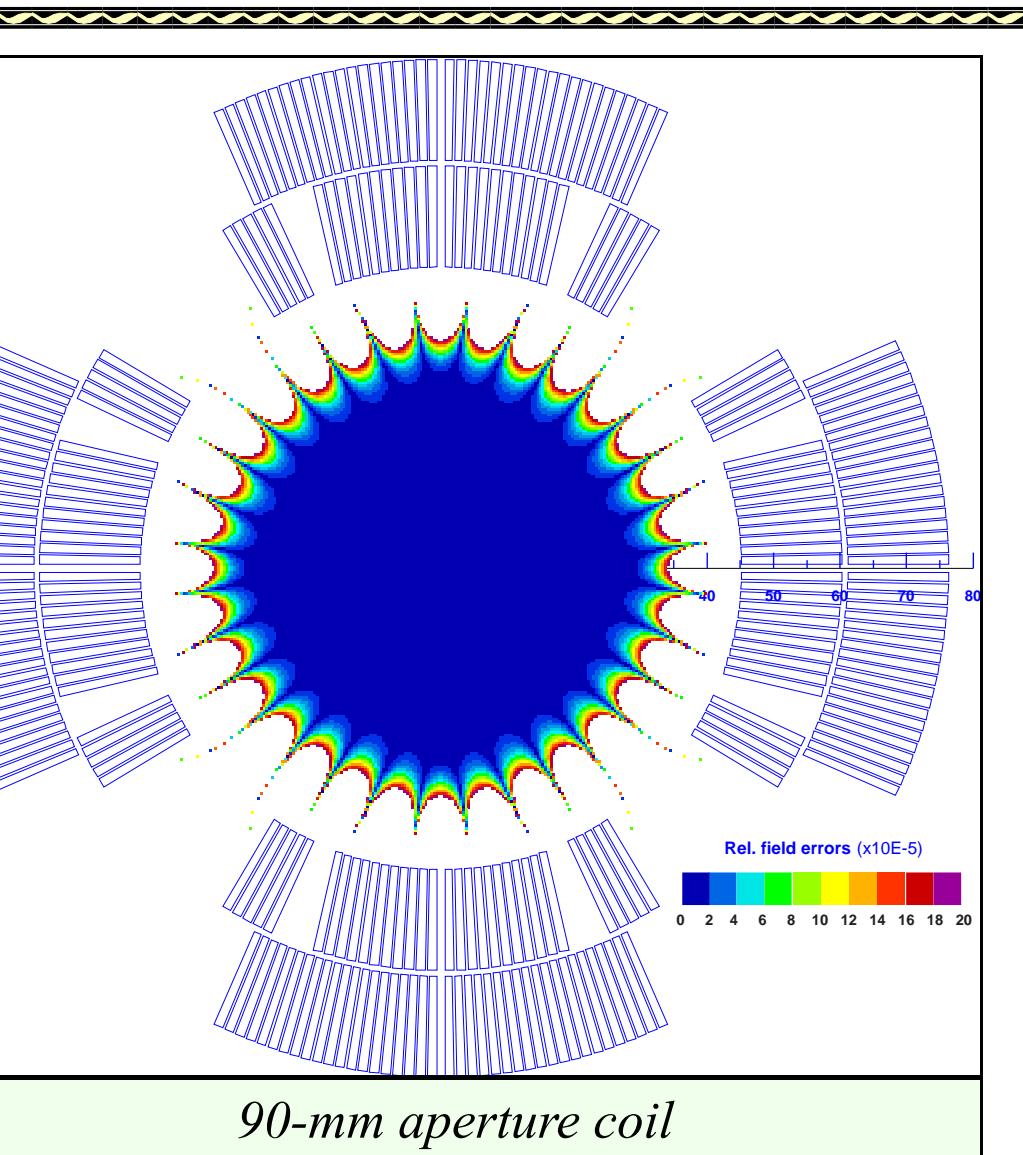
- 1st generation magnets have limited life time (~6 years) and will be one of the limiting factors for the machine performance.

The LARP provides the first chance to operate high field magnets based on Nb₃Sn technology in an accelerator.

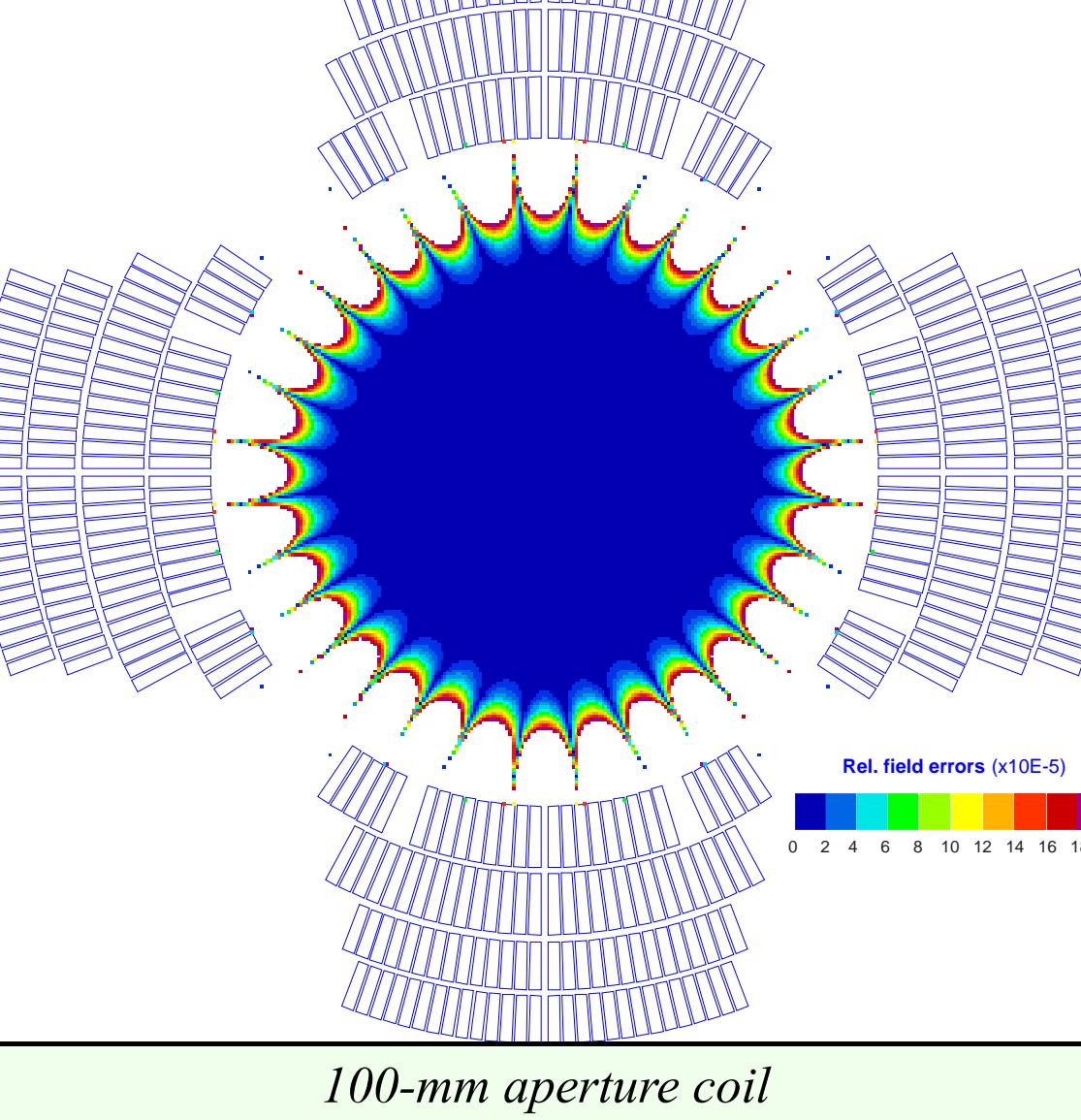
Contributions of Fermilab to LARP Magnet R&D include:

- participation in program proposal to DOE FY2002-2003;
- conceptual designs studies of different magnet types for 2nd generation high luminosity

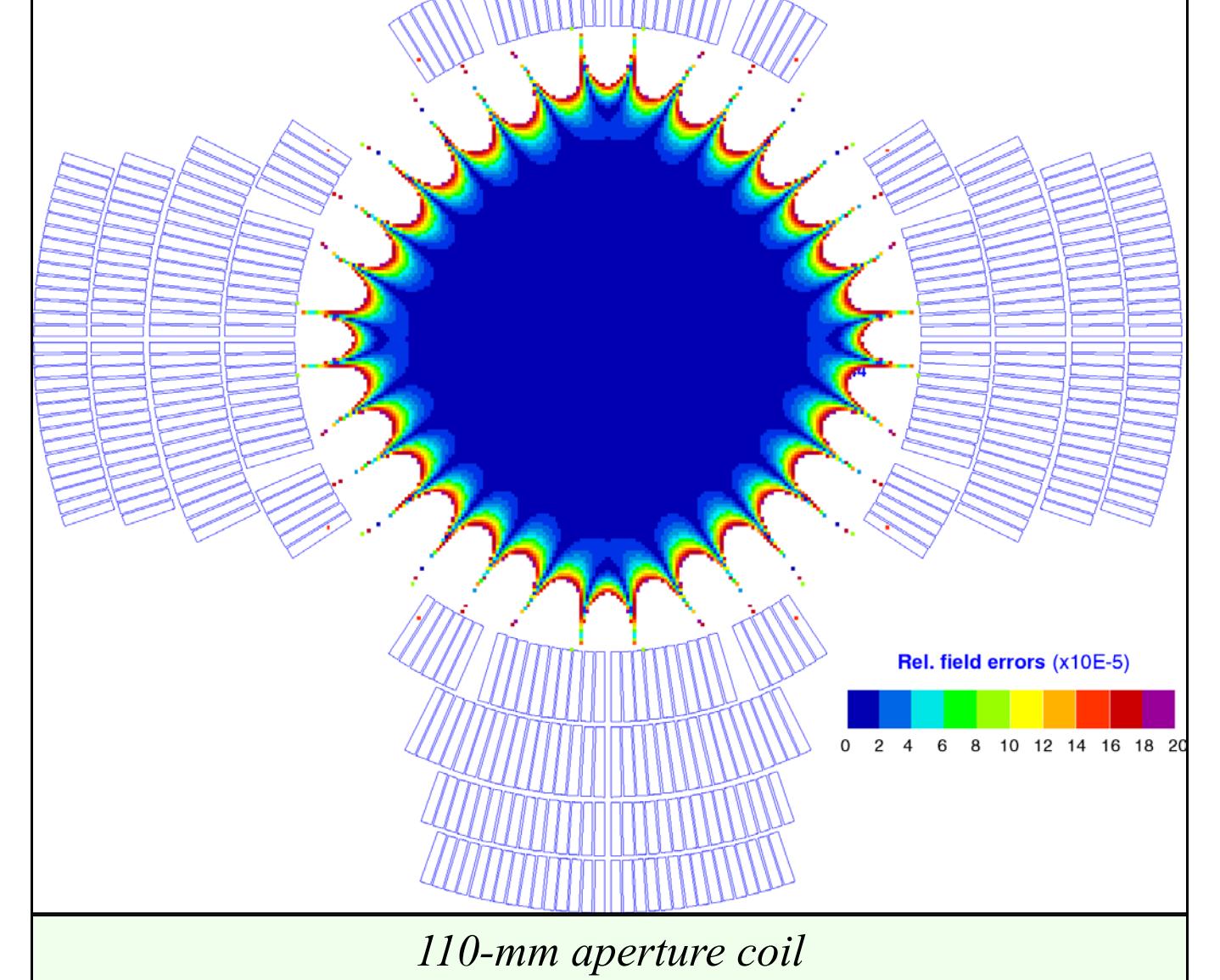
Starting from FY2005 when appropriate LARP funds are available, Fermilab will participate in R&D including the design, fabrication and test of models and prototypes of the LHC IR magnets.



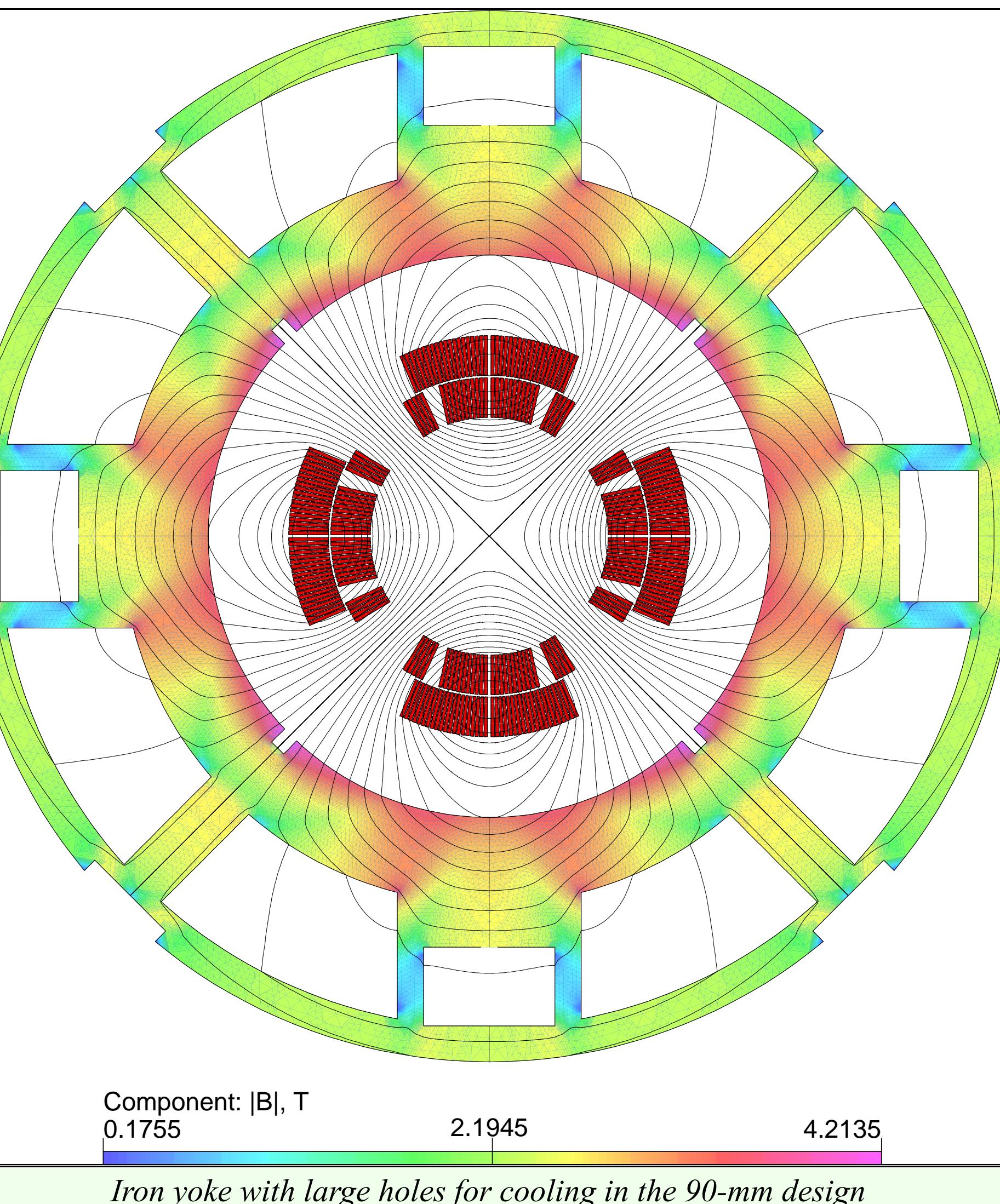
90-mm aperture coil



100-mm aperture coil

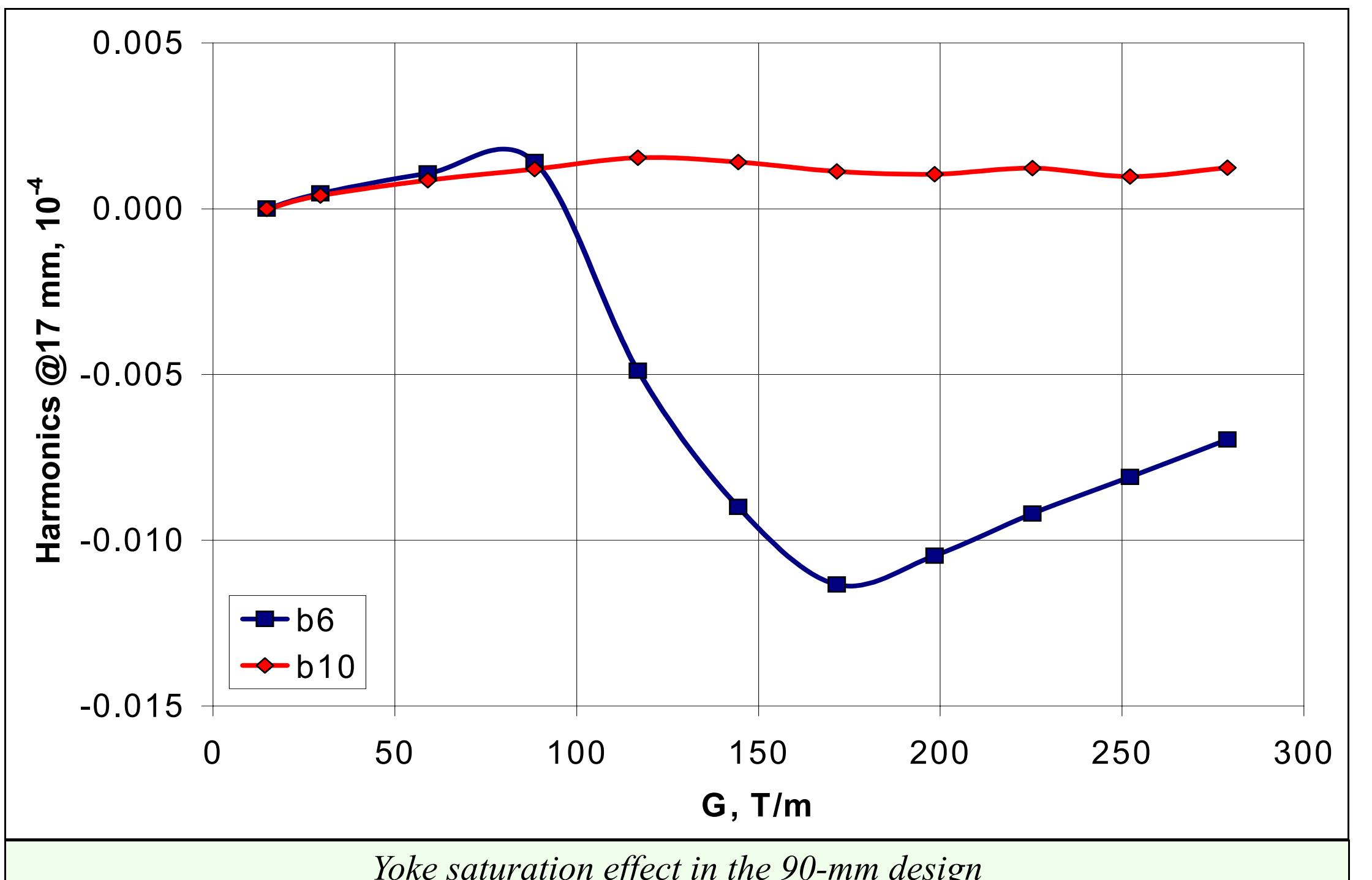


110-mm aperture coil

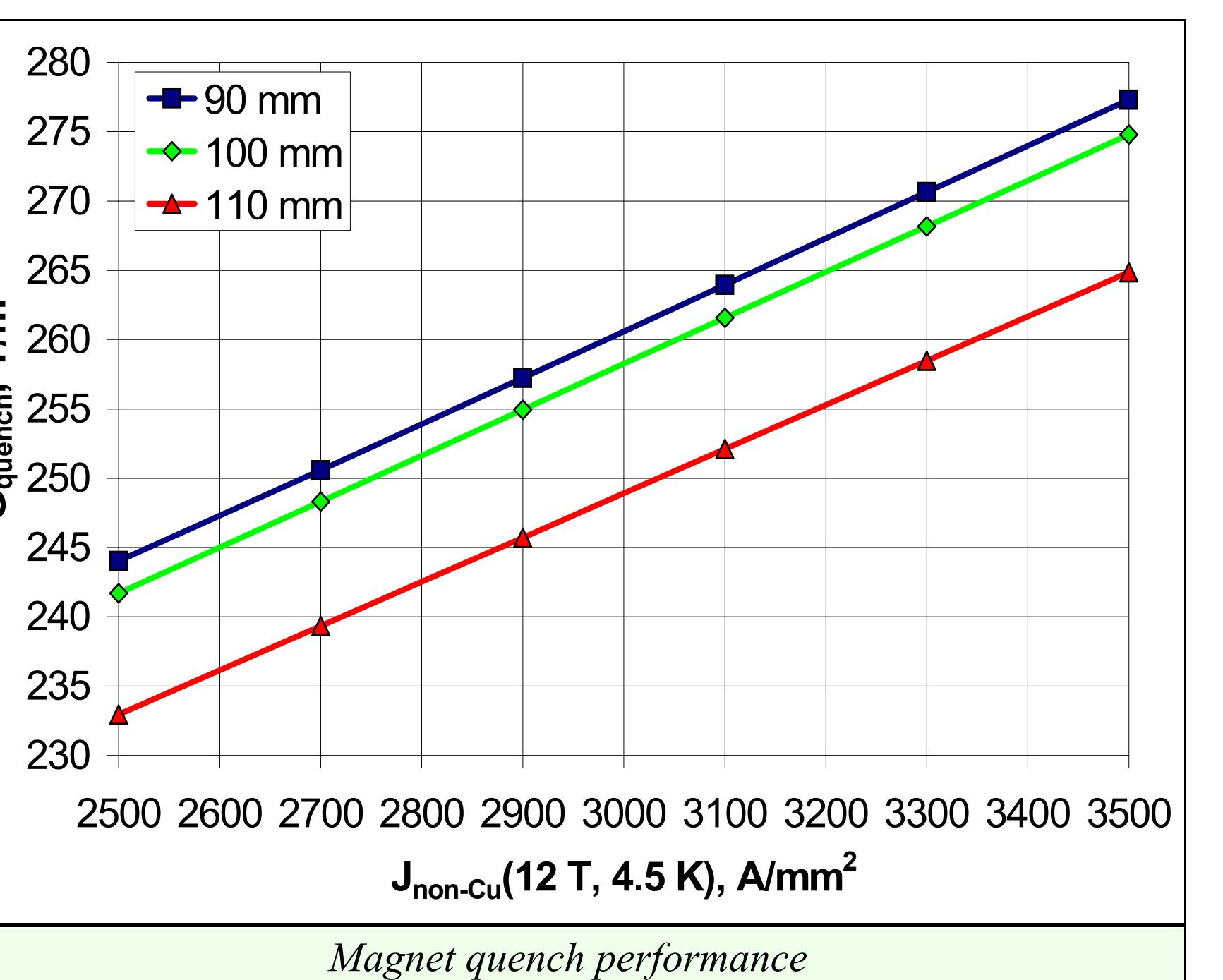


Iron yoke with large holes for cooling in the 90-mm design

n	b _n @ 17 mm			b _n @ R _{bore} /2		
	110 mm	100 mm	90 mm	110 mm	100 mm	90 mm
6	0.00003	0.00011	0.00018	0.00022	0.00053	0.00056
10	0.00007	0.00013	0.00048	0.00333	0.00286	0.00451
14	0.00004	0.00004	0.00024	0.01179	0.00456	0.00691
18	0.00000	-0.00001	-0.00005	-0.00317	-0.00359	-0.00468



Yoke saturation effect in the 90-mm design



Magnet quench performance

Parameter	Unit	Aperture size		
		110 mm	100 mm	90 mm
N of layers		4	4	2
N of turns		248	228	144
Coil area (Cu + nonCu)	cm ²	84.88	59.31	48.09
Non-Cu Jc at 12 T, 4.5 K	A/mm ²	3000	3000	3000
Quench gradient	T/m	248.9	258.2	260.6
Quench current	kA	14.13	12.31	17.64
Peak field in the coil at quench	T	15.28	14.51	13.50
Inductance	mH/m	17.46	14.71	4.86
Stored energy at 205 T/m	kJ/m	1181.4	702.9	468.2
Lorentz forces/I octant at 205 T/m				
Fx	MN/m	3.44	2.38	1.50
Fy	MN/m	-3.42	-2.39	-1.92